SEMI-ANNUAL STATUS REPORT

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entitled

INVISCID AND VISCID INTERACTION OF NON-ISOENERGETIC COMPRESSIBLE STREAMS IN EJECTORS AND THRUST AUGMENTATION SYSTEMS

for the period

1 FEBRUARY to 31 JULY 1965

DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING

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I. RESEARCH PERFORMED

A. Analytical Work

1.0 Supersonic Ejector Operating Characteristics

A comprehensive computer program for the analysis of supersonic ejector systems based on the flow model developed at the University of Illinois (Ref. 1, 2) is being developed (Section C-II of subject proposal). The basic guidelines being followed during the development of this program are:

i) to write the program independent of a particular compiler system in FORTRAN II language,

ii) to make the program reasonably self-explanatory,

iii) to present a unified analysis of the problem by combining various component sub-programs,

iv) to provide more generality in the configurations that can be analyzed, and

v) to decrease program operation time by improving numerous iteration loops as well as introducing suitable methods for finding approximate solutions.

This program is approximately 85% complete and checked out. A detailed description of the components of this program and their status is given in appendix A. A brief discussion of the salient features of this program is given now.

1.1 Computer Program Features

1.1.1 Ejector Geometry

The ejector shroud wall, at the option of the user, can be specified by two second-degree equations or by a set of shroud wall coordinates. In addition, the primary nozzle is assumed to produce either uniform or conical supersonic flow.

1.1.2 Ejector Solution Criteria

The subsonic and sonic secondary flow solutions are routinely found for "long" ejector shrouds based on the inviscid two-stream interaction. However, for "short" ejector shrouds, the solution requirement based on shroud length can now be treated.

Strict adherence to the solution criterion that the secondary stream reach sonic flow at the minimum secondary flow area significantly increases computational time because of slow convergence to the solution. Since the characteristics are relatively insensitive in the vicinity of the solution, an approximate method can be used to estimate the mass flow solution as well as the shroud wall pressure distribution for the sonic secondary flow case. This approach yields satisfactory results while significantly reducing computational time.

1.1.3 Static Thrust Characteristics

The integrated shroud wall pressure distribution along with the momentum fluxes of the primary and secondary streams are used to predict the static thrust characteristics of such a system (Ref. 3).

1.1.4 Inviscid and Viscid Interaction Components

The three flow regimes (Ref. 1, 2) which have been defined on the basis of the predominance of the inviscid and/or viscid interaction components are treated in a unified way. This has been achieved by incorporating these components and their respective solution criteria into a single program. In this way, the ejector characteristics for given geometry and flow conditions can be determined with a minimum amount of external intervention.

1.1.5 Wave Coalescence in Primary Flow Field

The coalescence of compression waves returning from the boundary of the primary stream is considered in the present program. The location of the internal shock is determined and the flow field calculations are modified to avoid "foldback." For the constant pressure boundary case, this program produces results which are in agreement with those presented in reference 4.

1.1.6 Shroud Wall Boundary Layer

Based on the theoretical inviscid shroud wall Mach number distribution, the approximate force contributions of the shroud wall boundary layer can be predicted. The significance of the boundary layer contribution to the system drag is presented in reference 3 for a typical thrust augmentation system.

2.0 Intake - Ejector Matching

A technique for matching intakes whose operating characteristics are defined by either experimental or theoretical means to the theoretical pumping characteristics of an ejector system has been developed. This technique can be utilized to predict the in-flight thrust characteristics of a thrust augmentation system (Ref. 3).

B. Experimental Work

1.0 Thrust Augmentation Systems (Tables I and II of subject proposal)

The apparatus and models to be used in the investigation of mass flow and static thrust characteristics of several ejector configurations have been designed and will be fabricated in the near future.

The high-temperature air supply system which is to be used in conjunction with these tests has been installed and will be operational in the near future.

Since submission of the subject proposal, the U. S. Army Missile Command, Redstone Arsenal, Alabama, has initiated contractual negotiations which will provide the Department of Mechanical Engineering with a small scale hot jet test facility (LABROC VI, Astrosystems International, Inc.). In addition to our original commitments, a limited study of the following pertinent parameters is being planned. They are:

i) the primary stream stagnation temperature level (up to 5000 R),

ii) the primary stream specific heat ratio ($1.2 \leq K_p \leq 1.5$), and

iii) the primary stream gas constant.

2.0 Two-Stream Mixing

2.1 Two-Stream Mixing Test Facility

A two-dimensional test section has been fabricated and checked out. This test section presently has the following features:

i) The supersonic stream Mach number can be varied with four interchangeable nozzle blocks such that; M = 1.5, 1.75, 2.0, 3.0.

ii) The subsonic stream can be varied over the Mach number range of M = 0 to 1.

iii) The mixing region has a length of approximately 6 inches, and is maintained at a constant pressure by adjustment of wall inclination and two control valves.

A series of experiments, over a wide range of flow variables, has been conducted with this facility. However, the experimental analysis has been restricted to Schlieren observations and static pressure surveys.

2.2 Optical Analysis of the Two-Stream Flow Field

An interferometer system with six inch diameter optics has been designed. The orders for the mirror mounts (Tinsley Laboratories, Inc.) and optics (Gaertner Scientific Corporation) have been placed with delivery expected by 1 December, 1965.

II. FUTURE PLANS

1.0 Ejector Computer Programs

The present program will be completed and checked out. The program will then be utilized in the analysis of the configuration to be studied experimentally (Tables I and II of proposal). In addition, solutions for a variety of configurations will be compiled and these solutions will serve as a basis for formulating and evaluating the usefulness of approximate functional relationships based on curve fitting techniques.

Further refinements and extensions to the program, which deal with more generalized secondary flow conditions, and the analysis of in-flight thrust augmentation characteristics will be considered.

2.0 Thrust Augmentation Experiments

The models and associated equipment will be fabricated in the near future. The cold and hot flow experiments will then be conducted.

3.0 Two-Stream Mixing

3.1 Surveys of the mixing region will first be conducted with a pitot tube probe. These data will provide preliminary information on the velocity profiles at several locations downstream of the confluence point.

3.2 Hot wire anemometer studies will produce information on the mean flow properties as well as the detailed structure of the turbulent mixing zone. The development and local distribution of the transport properties and dissipative mechanisms will be of special interest.

3.3 The interferometer system, upon delivery of the components, will be assembled, adjusted, and then utilized in the detailed optical analysis of the mixing region.

III. PUBLICATIONS

"Installed Performance of Air-Augmented Nozzles Based on Analytical Determination of Internal Ejector Characteristics," by Helmut H. Korst, A. L. Addy, and W. L. Chow. Presented at AIAA Propulsion Joint Specialist Conference, Colorado Springs, Colorado, June 1965. Paper No. 65-596 (Submitted to AIAA Journal of Aircraft for possible publication, July 1965)

IV. PARTICIPATING PERSONNEL

Appendix B lists the faculty members and graduate students that have participated under this Grant.

V. EXPENDITURES

Appendix C summarizes the current expenditures under this Grant.

VI. REFERENCES

1. Chow, W. L. and Addy, A. L., "The Interaction Between the Primary and the Secondary Streams of Supersonic Ejector Systems and Their Performance Characteristics." AIAA Journal, April 1964.

2. Chow, W. L. and Yeh, P. S., "Characteristics of Supersonic Ejector Systems With Non-constant Area Shroud," AIAA Journal, Vol. 3, pp. 526-527.

3. Korst, H. H., Addy, A. L., and Chow, W. L., "Installed Performance of Air-augmented Nozzles Based on Analytical Determination of Internal Ejector Characteristics," AIAA Paper No. 65-596, AIAA Propulsion Joint Specialist Conference, Colorado Springs, Colorado, June 14-18, 1965.

4. Vick, A. R., Andrews, E. H., Jr., Dennard, J. S., and Craidon, C. B., "Comparisons of Experimental Free-jet Boundaries with Theoretical Results Obtained with the Method of Characteristics," NASA-TN-D-2327, June 1964.

APPENDIX A

EJECTOR COMPUTER PROGRAM

The component programs used to calculate mass flow characteristics and pressure distributions in ejector configurations are listed and their status noted in this appendix.

1. Method of Characteristics Subroutines

   a) Field point subroutine (FPS)
      Status - operational

   b) Axis point subroutines (APS1 and APS2)
      Status - operational

   c) Family II - Wave Coalescence Subroutine (FIIWS)
      Status - operational

   d) Constant Pressure Boundary Subroutine (CPBS)
      Status - operational

2. Initial Primary Stream Calculation Subroutines

   a) Initial primary stream Prandtl - Meyer expansion (PMSBR)
      Status - operational

   b) Initial characteristic subdivision subroutines for conical or uniform flow (CNFLOC and UIEFLC)
      Status - operational

3. Inviscid Primary-Secondary Flow Interaction Subroutine

   a) Non-constant pressure boundary point subroutine (NCPBPS)
      Status - operational

4. Ejector Configuration Subroutines

   a) Shroud wall profile subroutine (SWPS)
      Status - operational

5. Iteration Subroutines

   a) Initial secondary Mach number iteration subroutine (EMSITR)
      Status - operational

b) Iteration for minimum area and Mach number equal 1.0 in secondary stream (ATEST)
Status - in progress

c) Iteration for Mach number equal 1.0 in short shroud ejector(EMNITR)
Status - in progress

d) Iteration to find intersection point of primary stream and shroud wall (CROSS)
Status - operational

6. Input-Output Subroutines

a) Input subroutines (INPT1E and INPT2E)
Status - operational

b) Output subroutines (OUT1E and OUT2E)
Status - operational

7. Turbulent Jet Mixing

a) Single-Stream and two-stream jet mixing subroutine (TJMIX)
Status - operational

b) Jet mixing integral subroutine (TEGRAL)
Status - operational

c) Error function (ERF)
Status - operational

8. Data Handling Subroutines

a) Data loading and storing subroutines (LOAD, STORE, and SDLOAD)
Status - operational

9. Miscellaneous Subroutines and Functions

a) Initial value subroutine (IVS1)
Status - operational

b) Pressure ratio across oblique shock (PRSHK)
Status - operational

c) Mach star as function of area ratio (EMSAR)
Status - operational

APPENDIX B

LIST OF PARTICIPATING PERSONNEL

I. Project Director: Dr. Helmut H. Korst
Professor of Mechanical Engineering
and Head of the Department of Mechanical
and Industrial Engineering
(NO CHARGE)

II. Consulting Scientist: Dr. W. L. Chow
Professor of Mechanical Engineering
(NO CHARGE)

III. Principal Investigator: Dr. A. L. Addy
Assistant Professor of Mechanical Engineering
February 16 to June 1, 1965 - Half Time
June 16 to August 15, 1965 - Full Time

IV. Research Assistants:

1) Thomas J. Marcisz
M.S. Degree Candidate in Mechanical Eng.
February 16 to June 1, 1965 - half time
June 16 to August 15, 1965 - one third time
Received M.S. Degree in M.E., August 1965
Now with TRW Space Technology Laboratories,
Redondo Beach, California

2) Vernon Roan
Instructor and Ph.D. Candidate in Aeronautical and Astronautical Engineering
(Formerly Senior Design Engineer and
Group Leader, Pratt and Whitney - Florida
Research and Development Center)
16 February to 15 June 1965 - NO CHARGE
16 June to 15 August 1965 - half time

3) Robert Eilers, Ph.D. Candidate in
Mechanical Engineering (Received M.S.
Degree, June 1963)
16 February to 15 June 1965 - Half time
16 June to 15 August 1965 - Full time